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**A TEST CASE GENERATION FRAMEWORK BASED ON UML
STATECHART DIAGRAM**



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Abstrak

Pengesanan awal kesalahan perisian menawarkan lebih fleksibiliti untuk membetulkan kesalahan tersebut pada peringkat awal pembangunan sistem. Malangnya, kajian sedia ada masih belum cukup menyeluruh dalam menerangkan proses utama penjanaan kes ujian secara automatik. Malahan algoritma yang digunakan dalam penjanaan ujian kes tidak disediakan atau diterangkan dengan jelas. Kajian semasa juga hampir tidak menangani isu gelung dan laluan selari, malahan kriteria liputan yang dicapai adalah rendah. Oleh itu, kajian ini mencadangkan satu kerangka penjanaan kes ujian yang menjana kes ujian yang diminimumkan dan diprioritaskan daripada gambarajah UML keadaan dengan kriteria liputan yang lebih tinggi. Kajian literatur telah dilaksanakan untuk mengenal pasti isu dan jurang yang berkaitan penjanaan kes ujian, pengujian berasaskan model, dan kriteria liputan. Kerangka yang dicadangkan ini direka bentuk hasil daripada maklumat yang dikumpul dan telah mengenalpasti lapan komponen yang mewakili proses dalam penjanaan kes ujian. Komponen tersebut adalah jadual hubungan, graf hubungan, pemeriksaan konsistensi, meminimumkan laluan ujian, memprioritaskan laluan ujian, pemangkasan laluan, penjanaan laluan ujian dan penjanaan kes ujian. Sebagai tambahan, satu prototaip untuk melaksanakan kerangka turut dibangunkan. Penilaian kerangka yang dibangunkan melibatkan tiga fasa: prototaip, perbandingan dengan kajian terdahulu dan ulasan pakar. Dapatan kajian menunjukkan kriteria liputan yang paling sesuai bagi gambarajah UML keadaan adalah liputan semua keadaan, liputan semua peralihan, liputan semua pasangan peralihan, dan liputan semua laluan gelung bebas. Selain itu, kajian ini mencapai kriteria liputan yang lebih tinggi dalam semua kriteria liputan yang dinyatakan di atas, kecuali liputan semua keadaan apabila dibandingkan dengan kajian sebelumnya. Hasil ulasan pakar menunjukkan bahawa pakar domain bersetuju bahawa kerangka yang dicadangkan ini adalah praktikal, mudah untuk dilaksanakan kerana kesesuaiannya dalam menjanaan kes ujian. Algoritma yang dicadangkan menghasilkan keputusan yang betul, dan prototaip berupaya menjana kes ujian dengan berkesan. Secara umumnya, sistem yang dicadangkan diterima baik oleh pakar berdasarkan aspek kebergunaan, kebolehgunaan, dan ketepatannya. Kajian ini menyumbang secara teori dan praktikal dengan menyediakan kerangka penjanaan kes ujian alternatif awal yang mencapai liputan yang tinggi dan dapat dilaksanakan dengan efektif menggunakan gambarajah UML keadaan. Kajian ini turut menambahkan pengetahuan baru dalam bidang pengujian perisian khususnya kepada proses pengujian dalam teknik berasaskan model, aktiviti pengujian, dan alat sokongan pengujian.

Kata kunci: Kerangka penjanaan kes ujian, liputan gelung, laluan selari, kes ujian yang diminimumkan, kes ujian yang diprioritaskan.

Abstract

Early software fault detection offers more flexibility to correct errors in the early development stages. Unfortunately, existing studies in this domain are not sufficiently comprehensive in describing the major processes of the automated test case generation. Furthermore, the algorithms used for test case generation are not provided or well described. Current studies also hardly address loops and parallel paths issues, and achieved low coverage criteria. Therefore, this study proposes a test case generation framework that generates minimized and prioritized test cases from UML statechart diagram with higher coverage criteria. This study, conducted a review of the previous research to identify the issues and gaps related to test case generation, model-based testing, and coverage criteria. The proposed framework was designed from the gathered information based on the reviews and consists of eight components that represent a comprehensive test case generation processes. They are relation table, relation graph, consistency checking, test path minimization, test path prioritization, path pruning, test path generation, and test case generation. In addition, a prototype to implement the framework was developed. The evaluation of the framework was conducted in three phases: prototyping, comparison with previous studies, and expert review. The results reveal that the most suitable coverage criteria for UML statechart diagram are all-states coverage, all-transitions coverage, all-transition-pairs coverage, and all-loop-free-paths coverage. Furthermore, this study achieves higher coverage criteria in all coverage criteria, except for all-state coverage, when compared with the previous studies. The results of the experts' review show that the framework is practical, easy to implement due to it is suitability to generate the test cases. The proposed algorithms provide correct results, and the prototype is able to generate test case effectively. Generally, the proposed system is well accepted by experts owing to its usefulness, usability, and accuracy. This study contributes to both theory and practice by providing an early alternative test case generation framework that achieves high coverage and can effectively generate test cases from UML statechart diagrams. This research adds new knowledge to the software testing field, especially for testing processes in the model-based techniques, testing activity, and testing tool support.

Keywords: Test case generation framework, loop coverage, parallel path, minimized test cases, prioritized test cases

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List of Abbreviations

BFS	Breath First Search
DFS	Depth First Search
EFSM	Extended Finite State Machine
FSM	Finite State Machine
GeMiTefSc	Generation and Minimization of Test Cases from State Chart
GTSC	Automated Generated Test Case Based on Statechart
IOCO	Input/Output Conformance
MBT	Model-based testing
OCL	Object Constraint Language
OMDAG	Object Method Acyclic Graph
OMG	Object Management Group
POS	Practical Swarm Optimization
PSO	Particle Swarm Optimization
RAD	Rapid Application Development
SAD	State Activity Diagram
SCCF	Statechart Coverage Criteria Family
SCOTEM	State COLlaboration TEST Model
SRT	State Relationship Table
SRG	State Relationship Graph
SUT	System Under Test
TCG	Test Cases Generation
TCGP	Test Case Generation Paths
TeGeMiOOSc	Test Generation and Minimization for O-O Software with State Charts
TFG	Test Flow Graph
TGV	Test Generation with Verification
UML	Unified Modelling Language
VDT	Vertex Description Table
XML	Extensible Markup Language

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This introductory chapter deliberates on the motivational aspects of software testing in general and automatic test case generation in practice, and focuses on using Unified Modelling Language (UML) diagrams as inputs to generate test cases.

This chapter presents the introduction to this study, beginning with the background of the study, which includes the background of software testing and automatic test case generation and the related literature. The next sections present the research problems, research questions, and research objectives. Subsequently, the scope of the research and the research framework will be discussed. Finally, the significance of the study and the terminologies will be presented. This chapter is concluded with an outline of the remaining chapters of this thesis.

1.2 Background of the Study

Computers and software are some of the major innovations in the history of mankind (Srivastav & Gupta, 2016). The use of computers plays a key role in the daily lives of people. The significant roles of computers in society and the increasing demand for complex computer applications makes software development difficult for software developers (Chavez, Shen, France, Mechling, & Li, 2016). Thus, the effort exerted and the cost of software development testing ultimately increases (Chen & Li, 2010).

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Appendix A
EXPERT EVALUATION FORM



EXPERT EVALUATION FORM

Dear Respected Respondent,

My name is Yasir Dawood Salman and I am currently pursuing my Ph.D. in Information Technology (IT). I am specializing in Software Testing at the School of Computing, College of Arts and Sciences, Universiti Utara Malaysia (UUM). My Ph.D. research entitled An Automated Test Case Generation Model for UML Statechart Diagram aims to develop a model and algorithms that can automatically generate test case from the UML statechart diagram.

Expert review is the verification method selected to evaluate this study. This study seeks your expertise in evaluating the proposed work. The information supplied will be treated as confidential and will be used for research purposes only and may be reported anonymously in academic publications. I humbly solicit for your kind assistance to participate in this research.

The main purpose of this verification is to verify the proposed model and its components, as well as other entities within the model, possesses a satisfactory range of accuracy, completeness, and consistency.

Kindly attach a copy of your CV after completion of this verification form for the proper documentation of this research.

If you have any questions regarding this research, please feel free to contact me by e-mail at yasir.dawod@gmail.com, phone number (+60169790922), or through my supervisor Dr. Nor Laily Hashim at laily@uum.edu.my.

Thank you for your time and assistance.

Instructions:

Please read the system review documents provided to you and go through the model, algorithms, and prototype carefully. Once this is done, please tick (✓) the most appropriate answer. You are advised to answer the questions based on your knowledge and experience and verify the items in Section B. This section on software quality dimensions is used to measure the originality and validity of the proposed system implementation for automatic test case generation of the UML statechart diagram. Section A is expert profile. This questionnaire is NOT intended to assess people, their work, or knowledge. Completing the questionnaire will take around 30–45 minutes. I will deeply appreciate if you could answer the questions carefully as the information you provide will influence the accuracy and success of this research.

Section A: Expert Profile

Name (First and Last)

Employer/ Facility

Position ☐ Professor ☐ Associate Professor ☐ Senior Lecturer ☐
Lecturer ☐ Others (Please specify).....

Fields of

Specialization

Years of Experience in:

Algorithms Software Software Software Testing
 Development Engineering

Research Interests

E-mail

Office Phone Mobile Phone

Section B: Items for Review

Please validate and give comments on the below mentioned dimensions on the proposed system (framework, algorithms and prototype) implementation for an automatic test case generation:



DIMENSIONS	DESCRIPTIONS	COMMENTS/SUGGESTIONS
Practicality	The proposed framework of automatic test case generation from UML diagrams can practically be implemented in the real world.	<input type="checkbox"/> Agree
		<input type="checkbox"/> Disagree
		Comments/ Suggestions:
		----- ----- -----
Clarity	As a whole, the framework is workable and the steps in the framework are easily followed.	<input type="checkbox"/> Agree
		<input type="checkbox"/> Disagree
		Comments/ Suggestions:
		----- ----- -----
Completeness	The essential items of the proposed framework are complete, satisfactory, and suitable to generate test cases.	<input type="checkbox"/> Agree
		<input type="checkbox"/> Disagree
		Comments/ Suggestions:
		----- ----- ----- -----

Correctness	The algorithms: State Relationships	<input type="checkbox"/> Agree
	Table (SRT), Test Cases Paths	<input type="checkbox"/> Disagree
	Generation (TCGP), minimization,	Comments/ Suggestions:
	prioritization, and Test Cases	-----
	Generation (TCG), provide correct	-----
	results and achieve its objectives.	-----
Effectiveness	The prototype automatically generates	<input type="checkbox"/> Agree
	the test cases from UML statechart	<input type="checkbox"/> Disagree
	diagram, for which it is intended.	Comments/ Suggestions:

Accuracy	The system provides correct test cases	<input type="checkbox"/> Agree
	result to the inputted UML statechart	<input type="checkbox"/> Disagree
	diagram.	Comments/ Suggestions:

Perceived Usefulness	The proposed system is useful for the	<input type="checkbox"/> Agree
	software tester in improving the	<input type="checkbox"/> Disagree
	coverage criteria quality of test case	Comments/ Suggestions:
	generation.	-----

Usability	Using the proposed system would <input type="checkbox"/> Agree make generating the test cases easy for <input type="checkbox"/> Disagree the software tester.	Comments/ Suggestions: ----- ----- ----- -----
Understand-ability	All documentations are clearly and <input type="checkbox"/> Agree simply written such that procedures, <input type="checkbox"/> Disagree rules, and algorithms are readable and can be easily understood.	Comments/ Suggestions: ----- ----- ----- -----

Universiti Utara Malaysia

Additional comments (if any):

.....

.....

.....

.....

Thank you.

..... Date.....

(Signature & Official Stamp)

Appendix B

CONSENT FOR PARTICIPATION IN EXPERT VERIFICATION

I volunteer to participate in a research project conducted by Yasir Dawood Salman, Ph.D. student, in Information Technology (IT), School of Computing, College of Arts and Sciences, Universiti Utara Malaysia (UUM).

I understand that the expert verification form is designed to evaluate the proposed framework, algorithms, and prototype. I will be one of approximately eight people being interviewed for this research.

1. My participation in this project is voluntary. I may withdraw and discontinue participation at any time. If I decline to participate or withdraw from the study, no one on my campus will be told.
2. The interview will last approximately 30-45 minutes. Notes will be written during the interview. An audio tape of the interview and subsequent dialogue will be made. If I do not want to be taped, I will need to inform in advance.
3. I understand that the researcher will not identify me by name in any reports using information obtained from this interview, and that my confidentiality as a participant in this study will remain secure. Subsequent uses of records and data will be subject to standard data use policies, which protect the anonymity of individuals and institutions.
4. I have read and understand the explanation provided to me. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this study.
5. I have been given a copy of this consent form.

_____	_____	_____
Name of Participant	Date	Signature
_____	_____	_____
Name of Researcher	Date	Signature

Appendix C

DETAILED MINIMIZATION AND PRIORITIZATION FOR SELECTED EXAMPLES

Section A: UML Statechart Diagram of an Online Shop

The process of minimize and prioritize the UML statechart diagram of an online shop example (see Section 5.2.2.1.2) is shown below.

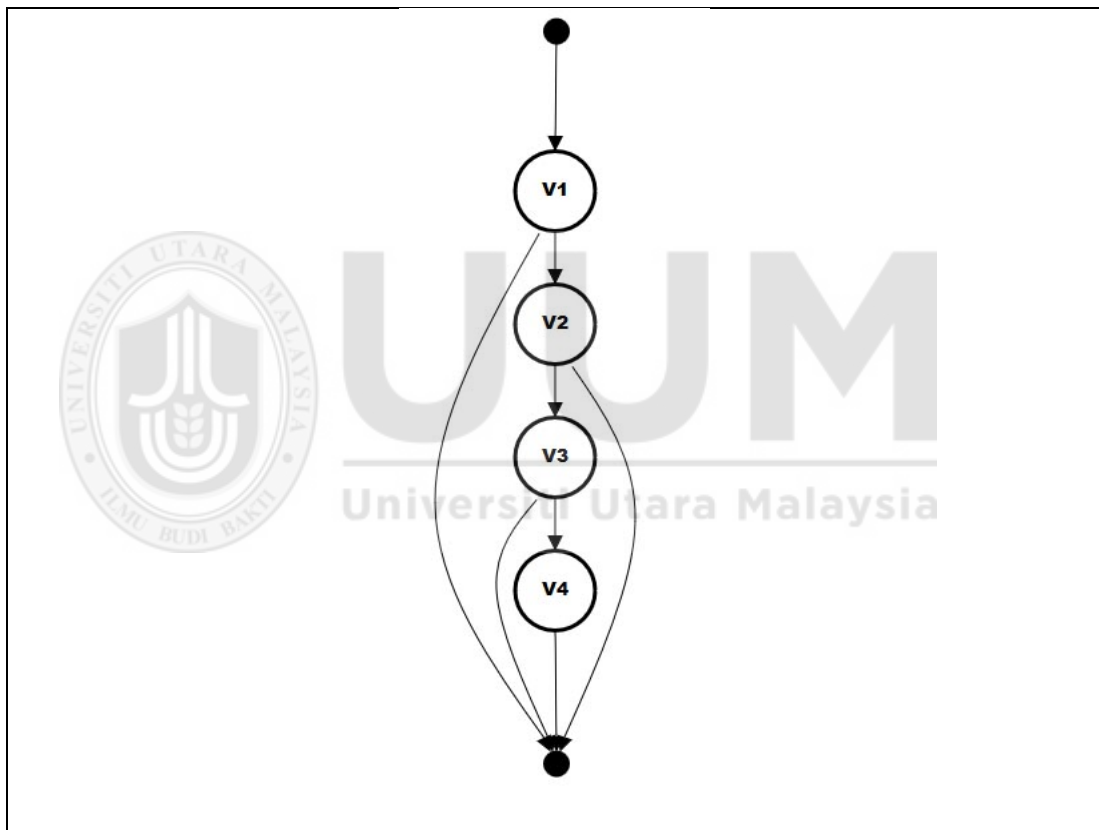


Figure B.1. Chart Relationship Graph for the UML Statechart Diagram of an Online Shop

The intermediate graph (Figure B.1) was converted to test paths using TCGP algorithm, and all the possible generated test paths from the intermediate graph is shown in Figure B.2.

TP 1: [S → 1 → 2 → 3 → 4 → E]
 TP 2: [S → 1 → E]
 TP 3: [S → 1 → 2 → E]
 TP 4: [S → 1 → 2 → 3 → E]

Figure B.2 All Possible Test Paths for the UML Statechart Diagram of an Online Shop

Path weight was calculated for each tests path using Equation 4.7, as shown in Table B.1, to determine each path weight of transactions in the system

Table B.1

Path Weight for Each Path for the UML Statechart Diagram of an Online Shop

TC	S→1	1→2	1→E	2→3	2→E	3→4	3→E	4→E	E	W_v
1	1	1	0	1	0	1	0	1	5	0.83
2	1	0	1	0	0	0	0	0	2	0.66
3	1	1	0	0	1	0	0	0	3	0.75
4	1	1	0	1	0	0	1	0	4	0.8

After generate the path weight, next step start by calculate path coverage for each single path as shown in Table B.2.

Table B.2

Coverage Criteria for Each Path for the UML Statechart Diagram of an Online Shop

TP No	All-State	All-Transition	All-Transition-pairs	All-One-loop-paths
1	100%	62%	50%	-
2	50%	25%	16%	-
3	66%	37%	33%	-
4	83%	50%	50%	-

After generate the path weight and coverage criteria for each path the intermediate graph is converted to adjacency matrix, as showing in Table B.3. Then, this matrix is used to generate the guidance matrix for the graph.

Table B.3

Adjacency Matrix for the UML Statechart Diagram of an Online Shop

States	0	1	2	3	4	5
0	0	1	0	0	0	0
1	0	0	1	0	0	1
2	0	0	0	1	0	1
3	0	0	0	0	1	1
4	0	0	0	0	0	1
5	0	0	0	0	0	0

After creating adjacency matrix, it is then used to generate guidance matrix. In the example in Figure 1, the number of vertices is 6, and the number of edges is 8, therefore the Cyclomatic Complexity equal to 4. However, the Cyclomatic Complexity for each vertex need to be calculated using Equation 4.9 to be used to calculate the guidance value using Equation 4.8. The results are shown in Table 4.

Table B.4

Guidance Value for the UML Statechart Diagram of an Online Shop

States	Cyclomatic Complexity CC	guidance value GF
0	4	196
1	4	156
2	3	87
3	2	38
4	1	9
5	1,000 [END vertex infinity]	1,000 [final state]

Guidance matrix (Table B.5) is just as a look-up/decision table of adjacency matrix with each guidance value corresponding to every edge.

Table B.5

Guidance Matrix for the UML Statechart Diagram of an Online Shop

States	0	1	2	3	4	5
0	0	156	0	0	0	0
1	0	0	87	0	0	1000
2	0	0	0	38	0	1000
3	0	0	0	0	9	1000
4	0	0	0	0	0	1000
5	0	0	0	0	0	0

Then the algorithm will generate the path sequences as:

Path 1= [0, 1, 2, 3, 4, 5],

Path 2= [1, 5],

Path 3= [2, 5],

Path 3= [3, 5].

To optimize the test cases, the algorithm will match each optimal path with paths in Figure B.2, and chose the lowest path weight W_v between the selected paths match paths. The minimized test paths are shown in Figure B.3

TP 1: [S → 1 → 2 → 3 → 4 → E]
TP 2: [S → 1 → E]
TP 3: [S → 1 → 2 → E]
TP 4: [S → 1 → 2 → 3 → E]

Figure B.3. Optimized Test Paths for the UML Statechart Diagram of an Online Shop

The combination use of these three paths lead to achieving: all-state coverage, all-transition coverage and, all-transition-pairs coverage as shown in Table B.6.

Table B.6

Coverage Criteria Percentage for the Minimized Paths for the UML Statechart Diagram of an Online Shop

TP No	All-State	All-Transition	All-Transition-pairs	All-One-loop-paths
1,2,3,4	100%	100%	100%	-

The ten generated fireflies for each state are showing in Table B.7.

Table B.7

Calculation of Brightness Values of 10 Fireflies

V	1		2		3		4		5		6		7		8		9		10	
	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i
0	6.	3.5	6.	3.5	6.	3.6	6.	3.6	6.	3.7	6.	3.7	6.	3.8	6.	3.8	6.	3.9	6	4
1	5.	2.0	5.	2.1	5.	2.1	5.	2.1	5.	2.2	5.	2.2	5.	2.3	5.	2.3	5.	2.3	5	2.
2	9	7	8	1	7	5	6	8	5	2	4	6	3	2	2	5	1	9	4	44
3	4.	2.8	4.	2.8	4.	2.9	4.	3.0	4.	3.0	4.	3.1	4.	3.2	4.	3.2	4.	3.3	4	3.
4	9	3	8	9	7	5	6	1	5	8	4	4	3	2	2	9	1	7	4	45
3	3.	4.1	3.	4.2	3.	4.3	3.	4.4	3.	4.5	3.	4.6	3.	4.8	3.	4.9	3.	5.1	3	5.
4	9	8	8	4.2	7	1	6	2	5	5	4	7	3	1	2	5	1		3	26
4	2.	14.	2.	15.	2.	15.	2.	16.	2.	16.	2.	17.	2.	17.	2.	18.	2.	19.	2	20
	9	71	8	15	7	63	6	13	5	67	4	24	3	86	2	52	1	23		

Table B.8 shows the separate calculation for cyclomatic complexity and information flow for each vertex, then show the Firefly brightness for that specific vertex after including the random factor.

Table B.8

Objective Function

Vertex	Cyclomatic Complexity CC	Information Flow IF_i	Firefly brightness A_i
0	4	0	3.94
1	4	4	2.26
2	3	4	3.29
3	2	4	4.31
4	1	1	14.71

By calculating the mean of brightness at every path using Equation 4.15, the results are shown in Table 9.

Table B.9

Test Path Prioritization for the Minimized Paths for the UML Statechart Diagram of an Online Shop

Test ID	Test path	Brightness value
TP 1	0 → 1 → 2 → 3 → 4 → 5	6.1010304355335
TP 4	0 → 1 → 2 → 3 → 5	4.6998174561816
TP 2	0 → 1 → 5	4.5997256564649
TP 3	0 → 1 → 2 → 5	4.4963083323801

In Table B.9 test paths mean of the brightness value is calculated for each generated optimized test path. From the table it is observed that optimized test path one has the highest brightness value and hence having high priority. Then the fourth path, the second path, and finely the third one.

Section B: UML Statechart Diagram of an Airline Check-in

The process of minimize and prioritize the UML statechart diagram of an airline check-in example (see Section 5.2.2.1.3) is shown below.

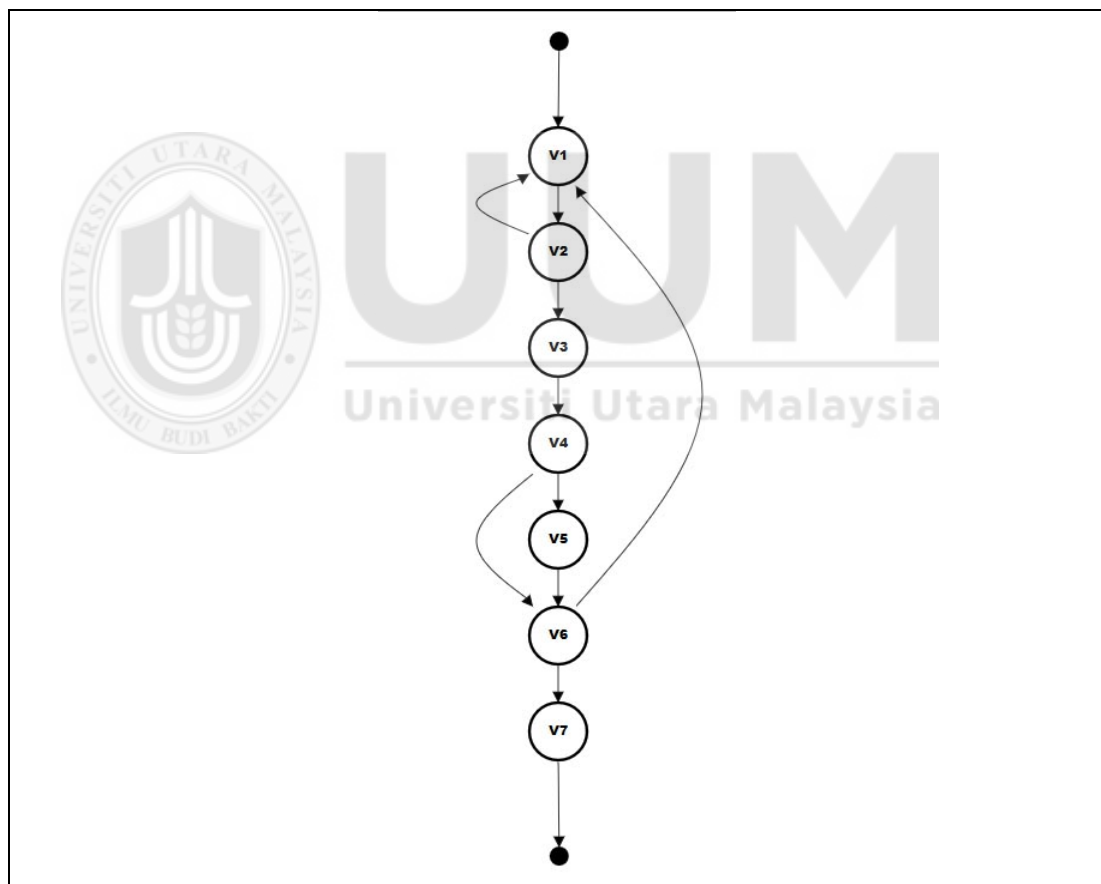


Figure B.4. Chart Relationship Graph of a UML Statechart Diagram of an Airline Check-in

The intermediate graph (Figure B.4) was converted to test paths using TCGP algorithm, and all the possible generated test paths from the intermediate graph is shown in Figure B.5.

TP 1: [S→1→2→3→4→5→6→7→E]
 TP 2: [S→1→2→3→4→6→7→E]
 TP 3: [S→1→2→3→4→5→6→1→2→3→4→5→6→7→E]
 TP 4: [S→1→2→3→4→5→6→1→2→3→4→6→7→E]
 TP 5: [S→1→2→3→4→6→1→2→3→4→5→6→7→E]
 TP 6: [S→1→2→3→4→6→1→2→3→4→6→7→E]
 TP 7: [S→1→2→1→2→3→4→5→6→7→E]
 TP 8: [S→1→2→1→2→3→4→6→7→E]

Figure B.5. All Possible Test Paths of a UML Statechart Diagram of an Airline Check-in

Path weight was calculated for each tests path using Equation 4.7, as shown in Table B.10, to determine each path weight of transactions in the system

Table B.10

Path Weight for Each Path of a UML Statechart Diagram of an Airline Check-in

TC	S→1	1→2	2→3	2→1	3→4	4→5	4→6	5→6	6→7	6→1	7→E	E	W_p
1	1	1	1	0	1	1	0	1	1	0	1	8	0.88
2	1	1	1	0	1	0	1	0	1	0	1	7	0.87
3	1	1	1	0	1	1	0	1	1	1	1	9	0.6
4	1	1	1	0	1	1	1	1	1	1	1	10	0.71
5	1	1	1	0	1	1	1	1	1	1	1	10	0.71
6	1	1	1	0	1	0	1	0	1	1	1	8	0.61
7	1	1	1	1	1	1	0	1	1	0	1	9	0.81
8	1	1	1	1	1	0	0	0	1	0	1	7	0.7

After generate the path weight, next step start by calculate path coverage for each single path as shown in Table B.11.

Table B.11

Coverage Criteria for Each Path of a UML Statechart Diagram of an Airline Check-in

TP No	All-State	All-Transition	All-Transition-pairs	All-One-loop-paths
1	100%	72%	25%	0%
2	88%	63%	25%	0%
3	100%	81%	50%	50%
4	100%	90%	75%	50%
5	100%	90%	50%	50%
6	88%	72%	50%	50%
7	100%	81%	50%	50%
8	88%	63%	25%	50%

After generate the path weight and coverage criteria for each path the intermediate graph is converted to adjacency matrix, as showing in Table B.12. Then, this matrix is used to generate the guidance matrix for the graph.

Table B.12

Adjacency Matrix of a UML Statechart Diagram of an Airline Check-in

States	0	1	2	3	4	5	6	7	8
0	0	1	0	0	0	0	0	0	0
1	0	0	1	0	0	0	0	0	0
2	0	1	0	1	0	0	0	0	0
3	0	0	0	0	1	0	0	0	0
4	0	0	0	0	0	1	1	0	0
5	0	0	0	0	0	0	1	0	0
6	0	1	0	0	0	0	0	1	0
7	0	0	0	0	0	0	0	0	1
8	0	0	0	0	0	0	0	0	0

After creating adjacency matrix, it is then used to generate guidance matrix. In the example in Figure B.4, the number of vertices is 9, and the number of edges is 11, therefore the Cyclomatic Complexity equal to 4. However, the Cyclomatic Complexity for each vertex need to be calculated using Equation 4.9 to be used to calculate the guidance value using Equation 4.8. The results are shown in Table B.13.

Table B.13

Guidance Value of a UML Statechart Diagram of an Airline Check-in

States	Cyclomatic Complexity CC	guidance value <i>GF</i>
0	4	316
1	4	276
2	4	236
3	3	147
4	3	117
5	2	58
6	2	38
7	1	9
8	1,000 [END vertex infinity]	1,000 [final state]

Guidance matrix (Table B.14) is just as a look-up/decision table of adjacency matrix with each guidance value corresponding to every edge.

Table B.14

Guidance Matrix of a UML Statechart Diagram of an Airline Check-in

States	0	1	2	3	4	5	6	7	8
0	0	276	0	0	0	0	0	0	0
1	0	0	236	0	0	0	0	0	0
2	0	276	0	147	0	0	0	0	0
3	0	0	0	0	117	0	0	0	0
4	0	0	0	0	0	58	38	0	0
5	0	0	0	0	0	0	38	0	0
6	0	276	0	0	0	0	0	9	0
7	0	0	0	0	0	0	0	0	1000
8	0	0	0	0	0	0	0	0	0

Then the algorithm will generate the path sequences as:

Path 1= [0, 1, 2, 3, 4, 6, 7, 8],

Path 2= [2, 1],

Path 3= [4, 5, 6, 1].

To optimize the test cases, the algorithm will match each optimal path with paths in

Figure B.5, and chose the lowest path weight W_p between the selected paths match

paths. The minimized test paths are shown in Figure B.6

TP 2: [S→1→2→3→4→6→7→E]
TP 4: [S→1→2→3→4→5→6→1→2→3→4→6→7→E]
TP 8: [S→1→2→1→2→3→4→6→7→E]

Figure B.6. Minimized Test Paths of a UML Statechart Diagram of an Airline Check-in

The combination use of these three paths lead to achieving: all-state coverage, all-transition coverage, all-transition-pairs coverage, and all-one-loop coverage as shown in Table B15.

Table B.15

Coverage Criteria Percentage for the Minimized Paths

TP No	All-State	All-Transition	All-Transition-pairs	All-One-loop-paths
2, 4, 8	100%	100%	100%	100%

The ten generated fireflies for each state are showing in Table B16.

Table B.16

Calculation of Brightness Values of the Ten Fireflies

V	1		2		3		4		5		6		7		8		9		10	
	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i
0	8.	2.7	8.	2.7	8.	2.7	8.	2.8	8.	2.	8.	2.8	8.	2.9	8.	2.9	8.	2.9	8	3.0
	9	3	8	6	7	9	6	2	5	86	4	9	3	2	2	6	1	9		3
1	7.	0.9	7.	0.9	7.	0.9	7.	1	7.	1.	7.	1.0	7.	1.0	7.	1.0	7.	1.0	7	1.0
	9	6	8	8	7	9	6	1	5	02	4	3	3	4	2	6	1	7	7	9
2	6.	1.7	6.	1.8	6.	1.8	6.	1.8	6.	1.	6.	1.9	6.	1.9	6.	1.9	6.	2.0	6	2.0
	9	8	8	1	7	3	6	6	5	89	4	2	3	5	2	8	1	1		4
3	5.	4.0	5.	4.1	5.	4.2	5.	4.2	5.	4.	5.	4.4	5.	4.5	5.	4.5	5.	4.6	5	4.7
	9	7	8	3	7	4.2	6	7	5	35	4	2	3	4.5	2	9	1	7		6
4	4.	2.8	4.	2.8	4.	2.9	4.	3.0	4.	3.	4.	3.1	4.	3.2	4.	3.2	4.	3.3	4	3.4
	9	3	8	9	7	5	6	1	5	08	4	4	3	2	2	9	1	7	4	5
5	3.	7.8	3.	8.0	3.	8.2	3.	8.4	3.	8.	3.	8.9	3.	9.1	3.	9.4	3.	9.7	3	10
	9	7	8	6	7	6	6	7	5	7	4	3	3	7	2	3	1	1		
6	2.	5.4	2.	5.6	2.	5.8	2.	6.0	2.	6.	2.	6.4	2.	6.7	2.	7.0	2.	7.3	2	7.6
	9	3	8	2	7	1	6	2	5	25	4	9	3	6	2	4	1	5		9
7	1.	20.	1.	21.	1.	22.	1.	23.	1.	25	1.	26.	1.	27.	1.	29.	1.	31.	1	33.
	9	83	8	74	7	73	6	81	5		4	32	3	78	2	41	1	25	1	33

Table B.17 shows the separate calculation for cyclomatic complexity and information flow for each vertex, then show the Firefly brightness for that specific vertex after including the random factor.

Table B.17

Objective Function

Vertex	Cyclomatic Complexity CC	Information Flow IF_i	Firefly brightness A_i
0	4	0	2.82
1	4	9	1.04
2	4	4	2.04
3	3	1	4.59
4	3	4	2.89
5	2	1	8.47
6	2	16	6.76
7	1	1	31.25

By calculating the mean of brightness at every path using Equation 4.15, the results are shown in Table B.18.

Table B.18

Test Path Prioritization of a UML Statechart Diagram of an Airline Check-in

Test ID	Test path	Brightness value
TP 2	0→1→2→3→4→6→7→0	8.3417877259468
TP 8	0→1→2→1→2→3→4→6→7→8	6.8306759195254
TP 4	0→1→2→3→4→5→6→1→2→3→4→5→7→8	6.7065188982599

In Table B.19 test paths mean of the brightness value is calculated for each generated optimized test path. From the table it is observed that optimized test second path has the highest brightness value and hence having high priority. Then the eighth path, and finely the fourth one.

Section C: UML Statechart Diagram for a Retail Point of Sale

The process of minimize and prioritize the UML statechart diagram for a retail point of sale example (see Section 5.2.2.1.4) is shown below.

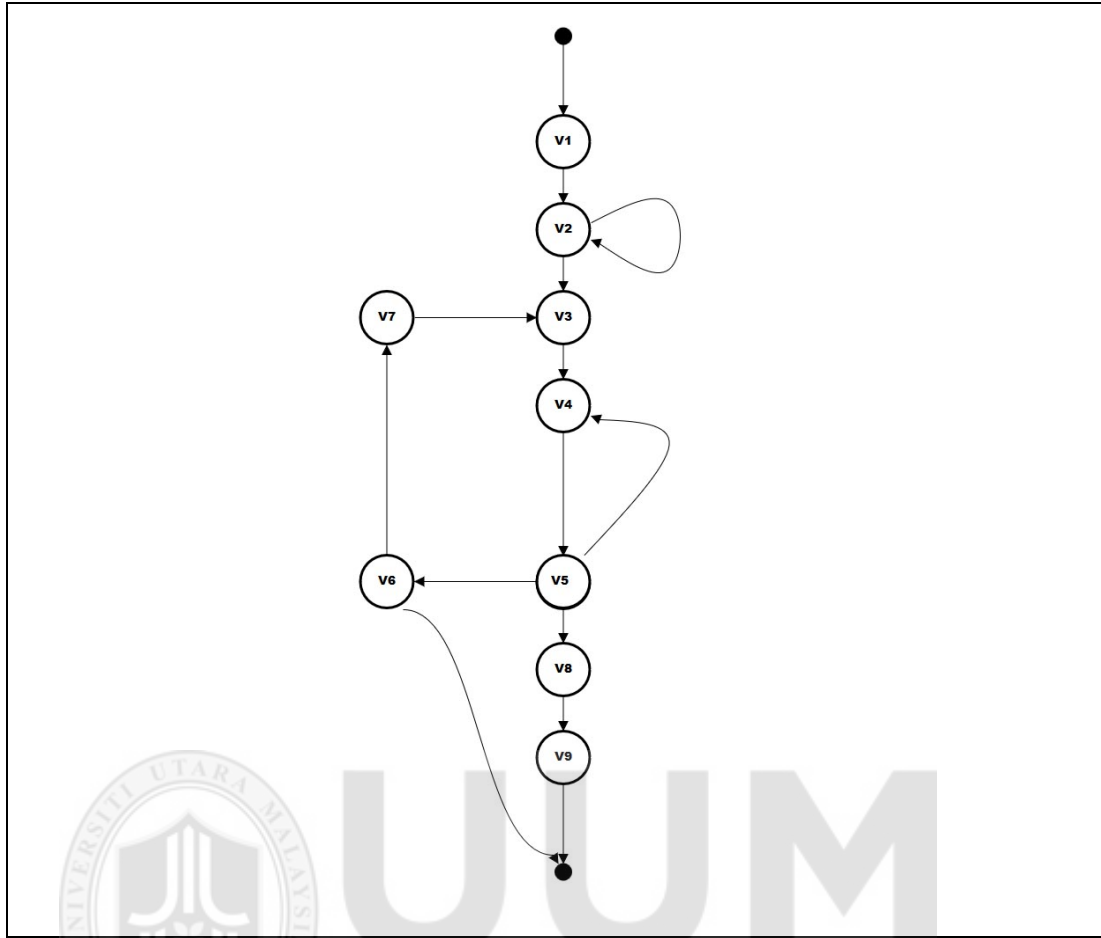


Figure B.7. Chart Relationship Graph for UML Statechart Diagram for a Retail Point of Sale

The intermediate graph (Figure B.7) was converted to test paths using TCGP algorithm, and all the possible generated test paths from the intermediate graph is shown in Figure B.8.

TP 1: [S→1→2→3→4→5→8→9→E]
 TP 2: [S→1→2→3→4→5→6→E]
 TP 3: [S→1→2→3→4→5→6→7→3→4→5→8→9→E]
 TP 4: [S→1→2→3→4→5→6→7→3→4→5→6→E]
 TP 5: [S→1→2→3→4→5→4→5→8→9→E]
 TP 6: [S→1→2→3→4→5→4→5→6→E]
 TP 7: [S→1→2→2→3→4→5→8→9→E]
 TP 8: [S→1→2→2→3→4→5→6→E]

Figure B.8. All Possible Test Paths for UML Statechart Diagram for a Retail Point of Sale

Path weight was calculated for each tests path using Equation 4.7, as shown in Table B.19, to determine each path weight of transactions in the system

Table B.19

Path Weight for Each Path for UML Statechart Diagram for a Retail Point of Sale

TC	S	1	2	2	3	4	5	5	5	6	6	7	8	9	E	W_v
	→	→	→	→	→	→	→	→	→	→	→	→	→	→		
	1	2	3	2	4	5	6	4	8	7	E	3	9	E		
1	1	1	1	0	1	1	0	0	1	0	0	0	1	1	8	0.88
2	1	1	1	0	1	1	1	0	0	0	1	0	0	0	7	0.87
3	1	1	1	0	1	1	1	1	1	1	0	1	1	1	12	0.85
4	1	1	1	0	1	1	1	1	0	1	1	1	0	0	10	0.76
5	1	1	1	0	1	1	0	1	1	0	0	0	1	1	9	0.81
6	1	1	1	0	1	1	1	1	0	0	1	0	0	0	8	0.8
7	1	1	1	1	1	1	0	0	1	0	0	0	1	1	8	0.9
8	1	1	1	1	1	1	1	0	0	0	1	0	0	0	8	0.88

After generate the path weight, next step start by calculate path coverage for each single path as shown in Table B.20.

Table B.20

Coverage Criteria for Each Path for UML Statechart Diagram for a Retail Point of Sale

TP No	All-State	All-Transition	All-Transition-pairs	All-One-loop-paths
1	81%	57%	28%	0%
2	72%	50%	42%	0%
3	100%	85%	42%	50%
4	81%	71%	57%	50%
5	81%	64%	42%	50%
6	72%	57%	57%	50%
7	81%	57%	42%	50%
8	72%	57%	57%	50%

After generate the path weight and coverage criteria for each path the intermediate graph is converted to adjacency matrix, as showing in table B.21. Then, this matrix is used to generate the guidance matrix for the graph.

Table B.21

Adjacency Matrix

States	0	1	2	3	4	5	6	7	8	9	10
0	0	1	0	0	0	0	0	0	0	0	0
1	0	0	1	0	0	0	0	0	0	0	0
2	0	0	1	1	0	0	0	0	0	0	0
3	0	0	0	0	1	0	0	0	0	0	0
4	0	0	0	0	0	1	0	0	0	0	0
5	0	0	0	0	1	0	1	0	1	0	0
6	0	0	0	0	0	0	0	1	0	0	0
7	0	0	0	1	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	1	0
9	0	0	0	0	0	0	0	0	0	0	1
10	0	0	0	0	0	0	0	0	0	0	0

After creating adjacency matrix, it is then used to generate guidance matrix. In the example in Figure B.7, the number of vertices is 11, and the number of edges is 14, therefore the Cyclomatic Complexity equal to 5. However, the Cyclomatic Complexity for each vertex need to be calculated using Equation 4.9 to be used to calculate the guidance value using Equation 4.8. The results are shown in Table B.22.

Table B.22

Guidance Value

States	Cyclomatic Complexity CC	guidance value GF
0	5	495
1	5	445
2	5	395
3	4	276
4	4	236
5	4	196
6	3	117
7	3	87
8	1	19
9	1	9
10	1,000 [END vertex infinity]	1,000 [final state]

Guidance matrix (Table B.23) is just as a look-up/decision table of adjacency matrix with each guidance value corresponding to every edge.

Table B.23

Guidance matrix

States	0	1	2	3	4	5	6	7	8	9	10
0	0	445	0	0	0	0	0	0	0	0	0
1	0	0	395	0	0	0	0	0	0	0	0
2	0	0	395	276	0	0	0	0	0	0	0
3	0	0	0	0	236	0	0	0	0	0	0
4	0	0	0	0	0	195	0	0	0	0	0
5	0	0	0	0	236	0	117	0	19	0	0
6	0	0	0	0	0	0	0	87	0	0	1000
7	0	0	0	276	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	9	0
9	0	0	0	0	0	0	0	0	0	0	1000
10	0	0	0	0	0	0	0	0	0	0	0

Then the algorithm will generate the path sequences as:

Path 1= [0, 1, 2, 3, 4, 5, 8, 9, 10],

Path 2= [2, 2],

Path 3= [5, 6, 7, 3],

Path 4= [5, 4],

Path 5= [6, 10].

To optimize the test cases, the algorithm will match each optimal path with paths in Figure B.8, and chose the lowest path weight W_p between the selected paths match paths. The minimized test paths are shown in Figure B.9.

TP 1: [S→1→2→3→4→5→8→9→E]
 TP 8: [S→1→2→2→3→4→5→6→E]
 TP 4: [S→1→2→3→4→5→6→7→3→4→5→6→E]
 TP 6: [S→1→2→3→4→5→4→5→6→E]

Figure B.9. Minimized Test Paths for UML Statechart Diagram for a Retail Point of Sale

The combination use of these three paths lead to achieving: all-state coverage, all-transition coverage, all-transition-pairs coverage, and all-one-loop coverage as shown in table B.24.

Table B.24

Coverage Criteria Percentage for the Minimized Paths

TP No	All-State	All-Transition	All-Transition-pairs	All-One-loop-paths
1, 8, 4, 6	100%	100%	100%	100%

The ten generated fireflies for each state are showing in Table B.25.

Table B.25

Calculation of Brightness Values of the Ten Fireflies

v	1		2		3		4		5		6		7		8		9		10	
	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i	d_i	A_i
0	11	1.6	11	1.6	11	1.6	11	1.6	11	1.7	11	1.7	11	1.7	11	1.7	11	1.7	1	1.7
	.9	5	.8	7	.7	8	.6	9	.5	1	.4	2	.3	4	.2	5	.1	7	1	9
1	10	1.5	10	1.5	10	1.5	10	1.5	10	1.5	10	1.5	10	1.5	10	1.6	10	1.6	1	1.6
	.9	1	.8	2	.7	3	.6	5	.5	6	.4	8	.3	9	.2	1	.1	2	0	4
2	9.	0.4	9.	0.4	9.	0.4	9.	0.4	9.	0.5	9.	0.5	9.	0.5	9.	0.5	9.	0.5	9	0.5
	9	8	8	8	7	9	6	9	5	4	3	1	2	1	2	1	2			3
3	8.	1.3	8.	1.4	8.	1.4	8.	1.4	8.	1.4	8.	1.4	8.	1.4	8.	1.5	8.	1.5	8	1.5
	9	9	8		7	2	6	3	5	5	4	7	3	8	2		1	2		4
4	7.	1.5	7.	1.5	7.	1.6	7.	1.6	7.	1.6	7.	1.6	7.	1.6	7.	1.7	7.	1.7	7	1.7
	9	6	8	8	7		6	2	5	4	4	6	3	8	2	1	1	3		5
5	6.	1.1	6.	1.1	6.	1.1	6.	1.1	6.	1.1	6.	1.1	6.	1.2	6.	1.2	6.	1.2	6	1.2
	9		8	2	7	4	6	5	5	7	4	9	3	1	2	3	1	5		7
6	5.	2.3	5.	2.4	5.	2.4	5.	2.4	5.	2.5	5.	2.5	5.	2.6	5.	2.6	5.	2.7	5	2.7
	9	6	8		7	4	6	9	5	3	4	8	3	2	2	7	1	2		8
7	4.	4.8	4.	4.9	4.	5.0	4.	5.1	4.	5.2	4.	5.3	4.	5.4	4.	5.6	4.	5.7	4	5.8
	9	5	8	5	7	5	6	5	5	6	4	8	3	9	2	2	1	5		8
8	3.	11.	3.	11.	3.	11.	3.	12.	3.	12.	3.	12.	3.	13.	3.	13.	3.	13.	3	14.
	9	36	8	63	7	9	6	2	5	5	4	82	3	16	2	51	1	89		29
9	2.	14.	2.	15.	2.	15.	2.	16.	2.	16.	2.	17.	2.	17.	2.	18.	2.	19.	2	20
	9	71	8	15	7	63	6	13	5	67	4	24	3	86	2	52	1	23		

Table B.26 shows the separate calculation for cyclomatic complexity and information flow for each vertex, then show the Firefly brightness for that specific vertex after including the random factor.

Table B.26

Objective Function

Vertex	Cyclomatic Complexity CC	Information Flow IF_i	Firefly brightness A_i
0	5	0	1.74
1	5	1	1.61
2	5	16	0.5
3	4	4	1.52
4	4	4	1.58
5	4	9	1.1
6	3	4	2.4
7	3	1	5.75
8	1	1	11.36
9	1	1	14.71

By calculating the mean of brightness at every path using Equation 4.15, the results are shown in Table B.27.

Table B.27

Test Path Prioritization for UML Statechart Diagram for a Retail Point of Sale

Test ID	Test path	Brightness value
TP 1	S→1→2→3→4→5→8→9→E	4.9599705586331
TP 4	S→1→2→3→4→5→6→7→3→4→5→6→E	2.6504048295212
TP 8	S→1→2→2→3→4→5→6→E	2.3697922355156
TP 6	S→1→2→3→4→5→4→5→6→E	2.3482365027468

In Table B.27 test paths mean of the brightness value is calculated for each generated optimized test path. From the table it is observed that optimized test path 1 has the highest brightness value and hence having high priority. Then the fourth path, the eighth path, and finely the sixth one.